Hydroacoustic Current Meters for the Measurement of Discharge in Shallow Rivers and Streams

Scott E. Morlock[1] and Gary T. Fisher, P.E.[2]

Abstract

The U.S. Geological Survey (USGS) is evaluating the use of hydroacoustic current meters for making discharge measurements in shallow rivers and streams. The USGS historically has made discharge measurements in shallow rivers using mechanical, impellor-type current meters attached to a wading rod. The evaluation project has focused on three categories of hydroacoustic meters: an acoustic Doppler velocimeter (ADV) called a Flowtracker[3], an acoustic Doppler velocity profiler (BoogieDopp), and bottom-tracking acoustic Doppler current profilers (ADCPs). The USGS role in this project includes providing USGS discharge-computation methods and algorithms to instrument manufacturers and evaluating instruments in the laboratory and field. An ADV (Flowtracker) designed for making discharge measurements in shallow rivers, has been tested in a USGS tow tank and was found to meet USGS calibration standards for mechanical, impellor-type current meters. The Flowtracker was field tested by USGS offices in five states; the tests were conducted by comparing discharge measurements made with the ADV to discharge measurements made with mechanical, impellor-type current meters. In general, the comparisons of Flowtracker performance to mechanical-meter results were favorable. An acoustic Doppler velocity profiler (BoogieDopp) is being evaluated for making discharge measurements in shallow rivers. The Boogiedopp will measure vertical velocity profiles at stationary positions across a channel, and the velocity profiles will be used to compute discharge. Discharge-computation software based on USGS methods and algorithms is under development for the acoustic Doppler velocity profiler. The USGS will evaluate bottom-tracking ADCPs from two manufacturers for making discharge measurements in shallow water. The bottom-tracking feature allows ADCPs to compute discharge from a moving platform as the platform moves across the channel.

Introduction

The U.S. Geological Survey (USGS) stream-gaging program provides streamflow data for a variety of purposes, including flood forecasting, water-resources planning and design, hydrologic research, and operation of water-resources projects (Wahl, Thomas, and Hirsch, 1995). Streamflow records are produced from more than 7,000 USGS stream-gaging stations across the Nation. The accuracy of streamflow records is dependent upon measurements of river and stream discharge made by USGS personnel. Fulford, 1990, showed that about 77 percent of 53,799 discharge measurements made by the USGS during the 1990 water year (October 1, 1989 to September 30, 1990) were wading measurements. The USGS is evaluating the use of

[1] U.S. Geological Survey, 5957 Lakeside Boulevard, Indianapolis, IN 46278 (smorlock@usgs.gov)
[2] U.S. Geological Survey, 8987 Yellow Brick Road, Baltimore, MD 21237 (gtfisher@usgs.gov)
[3] Use of trade or brand names in this paper is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey

hydroacoustic current meters for making discharge measurements in shallow rivers and streams. The role of the USGS in this shallow-water project includes

- providing standard USGS discharge-measurement methods and algorithms to vendors of hydroacoustic current meters;
- testing and evaluating hydroacoustic current meters;
- evaluating test results; and,
- developing technical guidance, recommendations, and policies for USGS users.

The USGS Instrument Committee (ICOM) and Office of Surface Water (OSW) Hydroacoustic Workgroup provide project oversight. ICOM, OSW, the Canadian Water Survey, and several USGS District offices have provided project funding.

The project is open to any vendor that manufactures hydroacoustic current meters that can be used for discharge measurements in shallow rivers and streams. Because the project budget is limited, vendors must be willing to commit their own instrument-development resources.

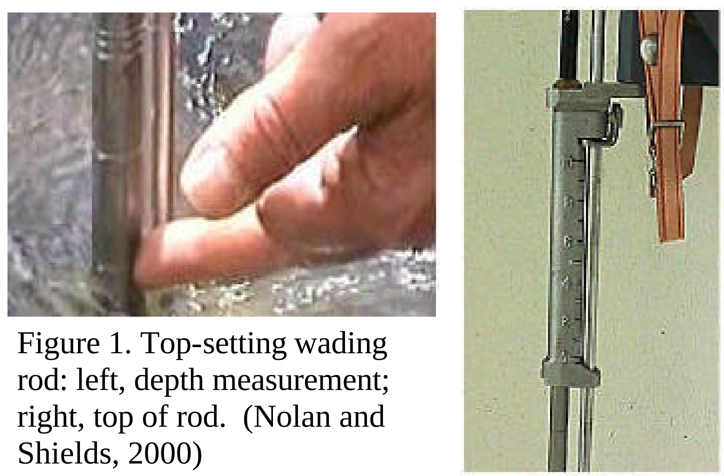


Figure 1. Top-setting wading rod: left, depth measurement; right, top of rod. (Nolan and Shields, 2000)

The USGS commonly uses the velocity-area method to measure discharge in streams and rivers (Wahl, Thomas, and Hirsch, 1995). The velocity-area method involves measuring the channel area and water velocities of a stream at a cross section that is perpendicular to the main flow of the channel. The channel is divided into a number of vertical subsections. The area and mean velocity in each subsection is measured and the subsection discharge is computed. The total discharge within the stream is the sum of the individual subsection discharges. For wading discharge measurements, a tag line with marks at known distance increments is strung across the channel perpendicular to the flow. The tag-line distance marks are used to determine subsection widths. Depths are measured with a standard USGS top-setting wading rod (fig. 1). A top-setting rod has a main rod marked with 0.10-ft (foot) increments for measurement of depth. A current meter is attached to a second sliding rod that is attached to the main rod. "Top-setting" refers to the fact that the second rod can be slid up and down; marks at the top of the rod allow a current meter to be set at .6, .2, or .8 of the water depth. The USGS commonly has used mechanical, propeller-type current meters to measure water velocities.

Mechanical meters have limitations, including: a shallow depth limit of 0.30 ft; a low velocity threshold of 0.1 ft/s (feet per second); extensive maintenance requirements to maintain meter accuracy; sensitivity to vertical velocities; and disturbance of the flow measured by the meter. These limitations can hamper the usefulness of mechanical meters, particularly at very low flows when streams can be shallow and slow. Alternatives to mechanical current meters for shallow-water discharge measurements are hydroacoustic current meters.

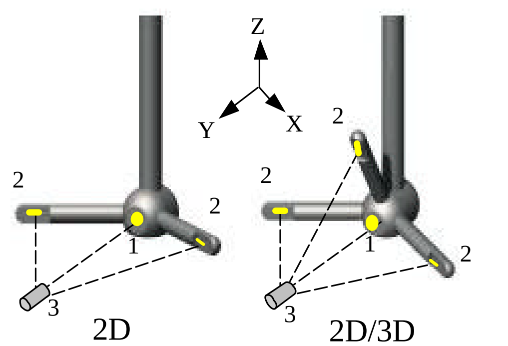
Hydroacoustic Current Meters

Hydroacoustic current meters use the Doppler principle applied to underwater sound to measure water velocities. Advantages of hydroacoustic current meters include no moving parts, simple maintenance; stable instrument calibration provided components are not damaged; low-velocity thresholds of less than 0.1ft/s; high sample and data-output rates; and quality-assurance data (not available for mechanical meters). Disadvantages of hydroacoustic current meters include higher purchase cost than mechanical meters; damage or malfunctions are not often field repairable; and degraded functionality in clear water.

Three types of hydroacoustic current meters are being evaluated for making discharge measurements in shallow rivers and streams: acoustic Doppler velocimeter (ADV); acoustic Doppler velocity profiler; and bottom-tracking acoustic Doppler velocity profiler, commonly called acoustic Doppler current profiler or ADCP.

Acoustic Doppler Velocimeter

An ADV model, the Flowtracker, was designed by SonTek/YSI to be used with the velocity-area discharge-measurement method. The Flowtracker was designed for mounting on a standard USGS top-setting wading rod (fig. 1).



1. Transmitting transducer
2. Receiving transducer
3. Sample volume

Figure 2. Flowtracker probe configurations showing components (courtesy of SonTek/YSI)

The Flowtracker probe configuration for this application is 2D or 2D/3D "side-looking" (fig. 2). To make discharge measurements, the probe is mounted so that the transmitting transducer acoustic beam is parallel to the tag line used to measure subsection widths. The Flowtracker computes velocities in XY (2D) or XYZ (3D) coordinates (fig. 2). The X-coordinate velocity is the velocity used to compute discharge and is perpendicular to the tag line. The Y-velocity component is the "across-stream" velocity parallel to the tag line. It is not used to compute discharge, but is used to quality assure the measurement (large Y-component velocities indicate large horizontal angles of flow with respect to the tagline; it is generally recommended that the instrument be used in flow angles of less than 20 degrees). The 2D/3D probe also provides a Z or vertical velocity that similarly can be used for quality assurance.

The Flowtracker probe is connected by a 2 m (meter) cable to a hand-held interface (fig. 3C). The interface contains the instrument electronics and has a keypad for data entry and a display. The interface allows an operator to configure the instrument for measurement, display pertinent measurement data, and store measurement data binary files. Flowtracker software allows users to download files from the interface to a personal computer and extract various data-summary files in text format. The Flowtracker has the following specifications: acoustic frequency, 10 Mhz (megahertz); sample frequency, about 10 Hz (hertz); output frequency, 1 Hz; sample volume distance from transmitting transducer, 10 cm (centimeters); manufacturer-published velocity accuracy, 1 percent of measured velocity.

The Flowtracker (fig. 3C) is the result of an iterative design process that began with a "proof-of-concept" (POC) ADV for wading discharge measurements (fig.3A). The POC ADV had a 2D/3D side-looking probe (fig. 2) attached by a short stem to a canister containing the instrument electronics, an external power-supply box, and a hand-held PC with custom software that allowed the input of subsection stations and depths. An adapter mounted the ADV on a wading rod. The POC ADV was cumbersome to use because of the attached probe-canister assembly and external power-supply box but proved the instrument could be used for wading discharge measurements.

Input from testing of the POC unit was used by the ADV manufacturer to design a "second-generation" prototype (fig. 3B) that was closer in appearance and functionality to the Flowtracker than the POC prototype.

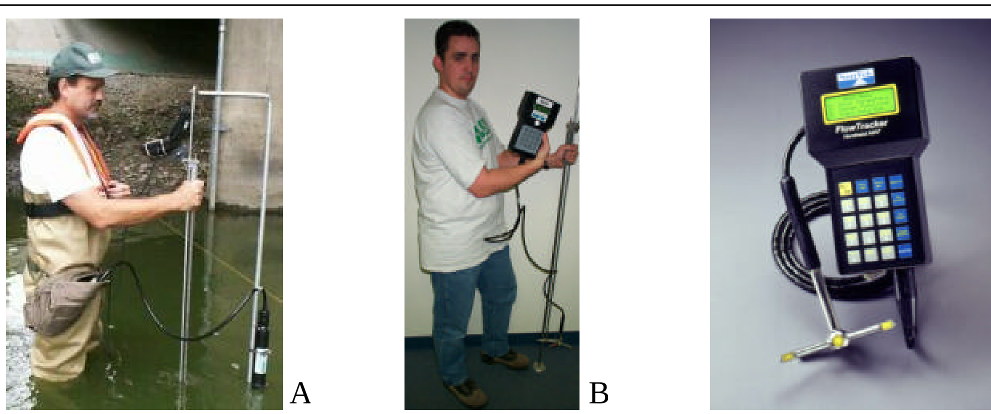

A B C

Figure 3. ADV evolution—A) USGS hydrographer making a discharge measurement with proof-of-concept prototype; B) USGS hydrographer with second-generation prototype; C) Flowtracker (Flowtracker photograph courtesy of SonTek/YSI)

The second-generation prototype was field tested in Indiana in January 2001 by making discharge measurements with the unit while concurrently making discharge measurements with mechanical meters at seven USGS stream-flow gaging stations. Discharges from the ADV and Price meters compared favorably. The second-generation prototype was tested in a tow tank at the USGS Hydraulics Laboratory at Stennis Space Center, Mississippi, in February 2001. The tests consisted of suspending the meter from a tow cart and towing it in still water. The tow-cart speed is used as a reference speed for testing meter velocity-measurement accuracy. The ADV was tested at tow-cart speeds ranging from about 0.1 to 5 ft/sec. The ADV was mounted at yaw (horizontal) angles of 0, 10, 20, 30, and 40 degrees during the tests. For 14 of the 21 runs at 0- and 10-degree yaw angles, ADV speeds were within 1 percent of the corresponding tow-cart speeds. With the exception of runs at 2.985 ft/s, runs above 0.248 ft/s were within 1 percent of the tow-cart speeds. Runs at 2.985 showed a gradually changing speed over the duration of the run—something that did not occur at other speeds. Vibration of the mounting apparatus has been proposed as a possible cause. Further runs at this speed at all other yaw angles produced similar results. For mounting angles at and greater than 20 degrees, ADV speed departures of about 1 to 20 percent were prevalent because of flow disturbance from the probes.

Results of the POC testing and input from persons who participated in the tests were used by SonTek/YSI in the design of the Flowtracker. The USGS has tested Flowtrackers in the laboratory and has conducted informal field tests.

Two Flowtrackers, serial numbers p66 and p75, were tested in April 2002 at the USGS Hydraulics Laboratory tow-tank facility. Tests were made with a standard calibration procedure for mechanical (Price AA) current meters: runs were made at tow-cart speeds of 0.15, 0.25, 0.50, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, and 8.0 ft/s. Allowable departures of Price AA meter from tow cart speed are: 0.25 ft/s, 6.0 percent; 0.50 ft/s, 3.4 percent; 0.75 ft/s, 2.5 percent; 1.00 ft/s; 2.0 percent; and 1.5 ft/sec and higher, 1.5 percent. Two tow-cart runs, in opposing directions (the first run is called “forward” and the second “reverse”), are made for each speed for a total of 20 runs. The Flowtrackers sampled velocities during the runs; the mean Flowtracker velocity during a run was used to compare to the tow-cart speed. The goal of the testing was to see if the Flowtrackers met accuracy limits for Price AA meters and the Flowtracker manufacturer-published accuracy limits (1 percent of measured velocity).

For the range of velocities, the mean departure of Flowtracker p66 velocity from tow-cart speed was -0.27 percent. The maximum departure was -6.7 percent for the 0.15 ft/s forward run. For 17 of 20 runs, p66 met accuracy limits for mechanical meters; for 15 of 20 runs p66 met the manufacturer accuracy limits. Flowtracker p66 met both Price AA meter and manufacturer accuracy limits for one run of every speed (those runs that did not meet accuracy limits were all reverse runs, except for the 0.15 ft/s forward run). For all runs at or below 0.75 ft/s, with the exception of the 0.15 ft/s forward run, p66 velocities equaled the tow-cart speed. For most runs Flowtracker p66 met Price AA meter and manufacturer accuracy limits.

A low-velocity bias of about 1.5 percent was discovered for Flowtracker p75; subsequent investigation by the manufacturer revealed a factory calibration error. This error was discovered for 3 of 100 Flowtrackers that had been manufactured. The manufacturer has taken steps to improve the factory calibration procedure to prevent future errors. With the bias, the mean departure of p75 velocity from tow-cart speed was -1.8 percent; 13 of 20 runs met mechanical meter-accuracy limits, and 3 of 20 runs met manufacturer accuracy limits. After application of a 1.5 percent correction factor to the Flowtracker velocities the mean departure of p75 velocity from tow-cart speed was -0.32 percent; 17 of 20 runs met Price meter accuracy limits and 13 of 20 runs met manufacturer accuracy limits. Because of the known problem and because the correction factor was approximate, the performance of p75 is not representative of Flowtracker performance.

Informal field tests were carried out with three Flowtrackers from August to October, 2001. A total of 29 Flowtracker discharge measurements were made; the tests took place in Alaska, Indiana, Ohio, Montana, and New York. Discharge measurements with other types of current meters (26 measurements were made with Price AA or pygmy current meters and 3 with electromagnetic current meters) were made concurrently with the Flowtracker measurements for comparison. The velocity-area method was used to make all measurements. Four of the comparison measurements were made with Price current meters in conditions that exceeded the meters' design limits (for example, velocities were below the meter low-velocity threshold). For the remaining 25 measurements, 15 Flowtracker measurement discharges were within 5 percent of the comparison measurement discharges and 20 were within 10 percent. The maximum difference between Flowtracker and comparison measurements was 13 percent; the mean difference (absolute value) was 5.2 percent. Discharges for the 25 measurements ranged from 2.4 to 388 ft^3/s (cubic feet per second). Ideally, the Flowtracker and the comparison meter would be used at the same horizontal stations and the same depths from the wading rod would be used to compute channel subsection areas. If different stations were used for different meters or if different depths were read, the area used to compute discharge would not be the same for Flowtracker and comparison measurement. This was the case for 19 of the 25 measurements. For the six remaining measurements, the computed channel areas for Flowtracker and comparison measurement matched; the percent differences (absolute value) between Flowtracker and comparison measurement were 1.8, 2.3, 3.4, 3.5, 5.6, and 11.7. These tests are not an indicator of Flowtracker measurement accuracy because there were differences in computed channel area between Flowtracker and comparison measurement for most measurements, redundant Flowtracker or comparison measurements were not made, and the calibration status of the comparison current meters was not known.

While not rigorous, the tests were useful. Flowtrackers were tested under a variety of conditions by a variety of USGS personnel. Personnel were able to provide valuable input for Flowtracker improvement. The algorithms used by the manufacturer to compute discharge from Flowtracker data correct. Flowtrackers were used in low signal-to-noise ratio (SNR) environments. While it is desirable to measure in water that produces SNR values of 10 or more, measurements from the informal test efforts were made with mean SNR values as low as 4 resulting in reasonable data. Several USGS personnel reported that measurements could not be completed because SNR values were below 3 and the data were not realistic; this occurred about 3 percent of the time.

The USGS started rigorous Flowtracker field-testing in late spring 2002. For comparison measurements, recently calibrated Price meters will be used. Measurements will not be made in conditions exceeding meter design limits. Redundant Price meter and Flowtracker measurements will be made; the same horizontal stations and depths will be used so that the same computed channel area is used for discharge computation for Flowtracker and comparison measurements. The first of these more rigorous tests took place in Kentucky the week of June 10, 2002. Two measurements were made with a Flowtracker and two with a recently calibrated Price AA meter; at a discharge of about 55 ft^3/s, all four measurements were within 1 percent of one another (David Mueller, oral communication, June 2002).

The USGS has purchased about 40 Flowtrackers. In October 2001 the USGS issued guidance to Flowtracker users that included a recommendation that all USGS offices quality assure their individual Flowtrackers. The USGS is drafting a technical memorandum that will provide more specific recommendations, guidelines, and policies after further field and laboratory testing has been completed.

Acoustic Doppler velocity profiler

The acoustic Doppler velocity profiler is a modified Aquadopp Current Profiler manufactured by Nortek. This instrument is called a "BoogieDopp" because it is designed to be deployed from a small "boogie board" floating platform. The BoogieDopp's transducer head (fig. 4) produces two beams fixed at an angle (referenced to vertical) of 25 degrees, one shallow-water beam fixed at an angle of 70 degrees and one vertical depth-sounding beam. To make a discharge measurement, the BoogieDopp is moved across the stream and held stationary at each vertical subsection while the instrument collects velocity profiles. The 25-degree beams will be used to collect profiles in depths greater than 1 ft. For shallower depths, the shallow-water beam has potential to collect velocity profiles; however, issues concerning known velocity biases with the shallow beam need to be investigated extensively before this beam is used. From the velocity profile, a mean velocity is computed for each subsection. The instrument also measures depth at each subsection using the vertical depth beam. Horizontal subsection distances are entered into a Windows CE based hand-held computer, called a personal data assistant or PDA. The PDA program uses USGS algorithms with the velocity-area method to compute discharge from the measured subsection velocities, measured depths, and entered horizontal subsection distance. The PDA also is used to configure the instrument and to collect and store of all instrument data. Communications between the PDA and BoogieDopp will be accomplished using radio modem telemetry (a standard BoogieDopp will have a radio modem built into the pressure case). The PDA will provide a computation of total discharge immediately following a measurement; the user also will have the opportunity to post-process the measurement data for quality-assurance purposes, using personal computer (PC) based software.

Specifications for the Boogiedopp are acoustic frequency, 2 MHz; ping rate, 23 Hz; data output rate, once every 3 to 4 seconds; blanking distance, minimum 5 cm; depth cell size, minimum 10 cm; manufacturer-published velocity accuracy, 1 percent ± 0.016 ft/s. The BoogieDopp is equipped with a compass and tilt sensor to compensate for the effects of pitch and roll.

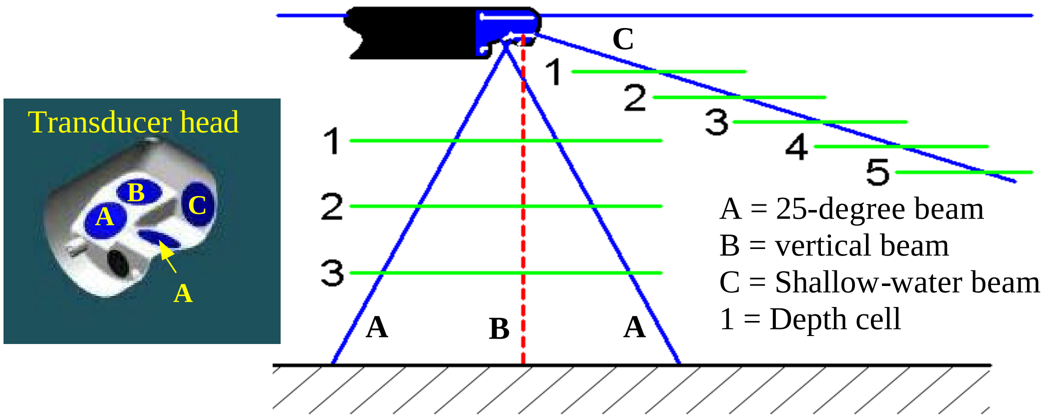


Figure 4. Conceptual sketch showing BoogieDopp operating principles and detail of the transducer head (courtesy of NortekUSA)

In July 2000, a proof-of-concept test was conducted with a standard Nortek Aquadopp. The Aquadopp was tested at a USGS streamflow-gaging station in August 2000 on a stream in the Indianapolis Metropolitan Area. The Aquadopp was mounted on a small floating platform (fig. 5). A pair of radio modems provided data communication between the Aquadopp and the manufacturer's data-acquisition software. The Aquadopp was floated from subsection to subsection. At each subsection, data were collected for 5 minutes. The data was post-processed to compute discharge, using standard extrapolation methods to estimate discharge in the unmeasured zones. The discharge computed from the Aquadopp data was 63.8 ft^3/s, while the discharge computed from the USGS streamflow-gaging station stage-discharge rating was 63.0 ft^3/s, a difference of 1.2 percent.

Figure 5. Acoustic Doppler velocity profiler proof-of-concept test

Based on the Aquadopp testing and input from the USGS, the manufacturer developed the first BoogieDopp. A boogie board platform designed specifically for the BoogieDopp was developed by the OceanScience Group (fig. 6). The platform is designed so that the BoogieDopp is recessed into the bottom of the board, minimizing drag from the instrument and maintaining a constant transducer draft of about 2 cm.

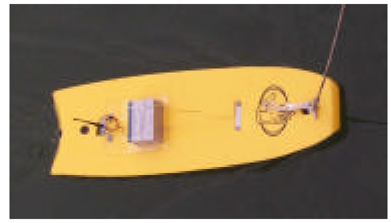


Figure 6. BoogieDopp floating platform

Testing of the BoogieDopp has included measurements in the field and tests in the USGS Hydraulics Laboratory tow tank. The USGS Hydro 21 committee (Hydro 21 has been formed to search out new technologies that may replace present field procedures for collection of physical and chemical data) used a BoogieDopp to make discharge measurements and collect velocity profiles at the USGS streamflow-gaging station, San Joaquin River near Vernalis, California, for periods during March, April, and May 2002. Overall, the BoogieDopp discharge measurements compared favorably to discharge measurements made with an RD Instruments acoustic Doppler current profiler (ADCP) and to discharges computed from the streamflow-gaging station stage-discharge rating (Ralph Cheng, US Geological Survey, oral communication, June 2002). In June 2002, a BoogieDopp discharge measurement was made at the Conrock Outflow in the Orange County Water District (OCWD), California. The Conrock Outflow is a rectangular concrete channel that connects several lakes. At a discharge of 44.2 ft^3/s, the mean discharge of a series of six discharge measurements was within 1 percent of the discharge measured during a concurrent Price AA discharge measurement made by OCWD personnel (Lee Gordon, NortekUSA, written communication, June 2002). A BoogieDopp was tested in spring 2002 at the USGS Hydraulics Laboratory; the test results are still under analysis.

The USGS plans to continue Boogiedopp field and laboratory testing throughout summer 2002. At this time the shallow-depth limit of the BoogieDopp is about 1 ft. The shallow-water beam will continue to be tested to see if shallower water can be measured. Further investigation is also required regarding possible low-velocity biases in the first one or two depth cells caused by flow disturbance from the instrument. The maximum range of the BoogieDopp is 16 to 39 ft, depending on backscatter; thus the instrument will be able to be used in deeper streams and rivers as well. Because it does not bottom track, the Boogiedopp will be immune to negative discharge biases caused by moving streambeds.

<u>Acoustic Doppler Current Profilers</u>

The USGS has been measuring river discharge with ADCPs since the early 1990s (Oberg and Mueller, 1994) and ADCP use has become commonplace within the USGS. ADCP use has been confined mainly to rivers with depths greater than about 4 ft . Because of recent advances in ADCP technology, these instruments have the potential to be used in shallower rivers. There are two commercially-available ADCP models from two manufacturers: the RD Instruments Rio Grande broadband ADCP and the SonTek RiverSurveyor narrowband ADCP. Both manufacturers offer a variety of instrument configuration and acoustic frequencies. The best suited for shallow-water applications are the RDI Instruments 1200 kHz (kilohertz Rio Grande and the SonTek 5 MHz

RiverSurveyor. Both instruments are commercially available. The RD Instruments Rio Grande, when used according to current USGS guidelines, has a minimum depth limit of about 2.5 to 3.0 ft (using Water Mode 5 with a 25 cm blanking distance and 5 cm depth cells) and a maximum depth range of about 60 ft. The SonTek 5 MHz RiverSurveyor has a minimum depth limit of about 1 ft and maximum depth range of about 4 ft. Both manufacturers have software designed for personal computers that is used for instrument deployment, data collection, and discharge computation; typically laptop computers are used in field-data collection.

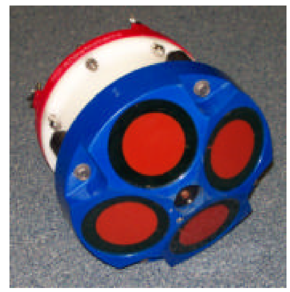


Figure 7. ZedHed ADCP

A special version of the RDI Instruments 1200 kHz Rio Grande called the "ZedHed" (fig. 7) has been designed to have very little transducer ringing and low blanking distances (manufacturer recommended minimum blank of 12 cm). A study spring 2002 study by Gartner and Ganju (2002) in rivers with surface velocities of about 2 to 3 ft/s indicated that flow disturbances caused by the ADCP transducer produced low velocity biases in depth cells up to 50 cm from the transducers. Gartner and Ganju suggest that, based on this study, users should set the blank so that the distance to the first depth cell is 0.5 times the expected current speed; this will avoid significant velocity biases. Gartner and Ganju also suggest that the ADCP deployment method may have an effect on the velocity bias. Use of an unmanned trimaran ADCP boat appeared to reduce the velocity-bias effect because the ADCP transducer head is recessed into the boat hull. The Gartner and Ganju study has important ramifications for use of the ZedHed ADCP in shallow water. If the 0.5-times current-speed blanking-distance estimate holds for slower velocities, low-velocity environments that are often prevalent in shallow streams would allow the user to use a lower blank. For example, at 0.8 ft/s a blank of 12 cm would be adequate. Use of Water Mode 5 with a 12-cm blank, 5-cm depth cells, and a transducer draft of 5 cm could allow the user to collect one or two depth cells in about 1 ft of depth. The 0.5-times current -speed estimate may not be linear with current speed and could be conservative at lower velocities; further analysis in slow-velocity regimes is needed. Minimizing the ADCP transducer draft and using a deployment platform designed to minimize flow disturbance will improve the shallow-water application. Considering these issues, the USGS shallow-water project will focus on testing in shallow, slow-velocity environments and evaluating ADCP deployment.

Figure 8. 5 MHz RiverSurveyor

The shallow-water project will be field testing a SonTek 5-Mhz RiverSurveyor (fig. 8) during summer 2002. No test data are yet available. Mueller (2002) tested a 3-Mhz RiverSurveyor on several rivers in Illinois and Indiana with average depths of about 3.6 ft and greater; he found that the average of discharges measured with the instrument was within 5 percent of measurements made with a Price AA meter. The issues related to the flow disturbance described for the RD Instruments unit will need to be addressed for the

SonTek instrument. Because of the high frequency of the RiverSurveyor, another concern is moving streambed. The shallow-water project will address these issues during field studies.

Summary and Conclusions

The USGS is evaluating hydroacoustic current meter technology for measuring discharges in rivers and streams at wading depths. Three categories of hydroacoustic current meters are being evaluated for making discharge measurements in shallow rivers and streams: acoustic Doppler velocimeter (Flowtracker), an acoustic Doppler velocity profiler (BoogieDopp), and bottom-tracking acoustic Doppler current profilers (ADCPs). The Flowtracker and BoogieDopp were developed with input from the USGS. Field and laboratory tests of the Flowtracker and preliminary field tests of the BoogieDopp indicate these instruments can meet or exceed USGS mechanical-meter standards when used under the proper conditions and when configured correctly. The use of ADCPs has become common throughout the USGS in deeper rivers and streams; recent advances in ADCP technology have produced several models with the potential for making moving-boat discharge measurements in shallow rivers and streams.

Each of the instruments being evaluated by the USGS shallow-water project has unique features for shallow water applications. The Flowtracker will operate in depths of less than 1 ft and low velocities (providing there is adequate backscatter). The BoogieDopp will operate in depths of about 1 ft or greater and is immune to the effects of moving streambed. ADCPs can be deployed from moving platforms, an advantage in that a single measurement (transect) can be completed relatively quickly, allowing more measurements per unit of time or producing better results in unsteady flow conditions.

References

Fulford, J.M., 1992, Characteristics of U.S. Geological Survey discharge measurements for water year 1990, U.S. Geological Survey Open-File Report 92-493.

Gartner, J.W., and Ganju, N.K., 2002, A preliminary evaluation of near-transducer velocities collected with low-Blank acoustic Doppler current profiler *in* Conference of Hydraulic Measurements and Experimental Methods, Estes Park, Colorado, 2002, Proceedings: Environmental and Water Resources Institute of the American Society of Civil Engineers.

Mueller, D.S., 2002, Field assessment of acoustic Doppler based discharge measurements *in* Conference of Hydraulic Measurements and Experimental Methods, Estes Park, Colorado, 2002, Proceedings: Environmental and Water Resources Institute of the American Society of Civil Engineers.

Nolan, K.M., and Shields, R.R., 2000, Measurement of stream discharge by wading: U.S. Geological Survey Water-Resources Investigations Report 00-4036, CD-ROM.

Oberg, K.A., and Mueller, D.S., 1994, Recent applications of acoustic Doppler current profilers *in* Fundamentals and Advancements in Hydraulic Measurements and Experimentation, American Society of Civil Engineers, p. 341-350.

Wahl, K.L., Thomas, Jr., W.O., and Hirsch, R.M., 1995, Stream-Gaging Program of the U.S. Geological Survey: U.S. Geological Survey Circular 1123, from http://water.usgs.gov/pubs/circ1123, accessed June 4, 2002.